Swift/UVOT Observations of Type Ib/c Supernovae

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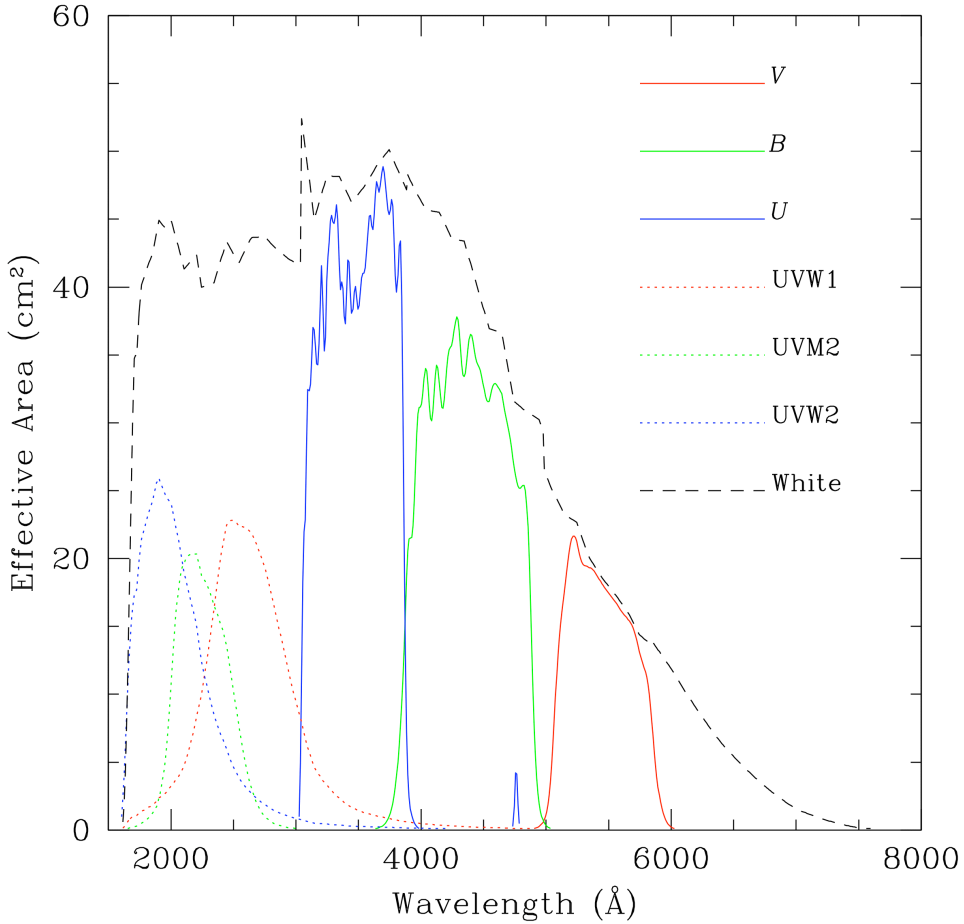
Introduction

The *Swift* observatory is uniquely suited for observing Type Ib/c supernvae (SNe). Its ultraviolet (UV) imaging and spectral capabilities (≈1700–3200 Å) (see Table 1) allow ultraviolet observations that can not be obtained with other telescopes. The satellite's rapid response capabilities make it possible to start taking observations of a supernova within one day of its discovery, which means that *Swift* can map the rising phase of the supernova light curve. As of mid-January 2007 *Swift* has observed eleven SNe Ib/c. These are listed in Table 2. Two of these, SN2006aj and SN2006jc have been followed for several weeks and have offered some insight into the nature of core collapse supernovae. The remaining SNe Ib/c were either too distant to allow the light curve to be monitored for a reasonable period of time, or were well past maximum light when *Swift* observations began.

SNe Ib/c have been linked to classical gamma-ray bursts. *Swift* observations will allow us to probe the connection between these two phenomena. The optical afterglows of most gamma-ray bursts are too faint, because GRBs tend to occur at high redshift, for *Swift* to observe a supernova component to the light curve. GRB 060218/SN2006aj was unusually close ($z = 0.0331$, $d_L = 145$ Mpc), so it could be followed from the initial GRB event to well past the maximum light of the SN.

There are currently only four satellites with UV imaging capabilities: *HST*, *Galex*, *FUSE*, and *Swift*. *Swift* is the only observatory capable of obtaining narrow-band UV images between 1700 Å and 3200 Å. Further, UVOT's UV filters are less than 1000 Å wide. It is the only observatory that can observe a SN within a day of its discovery. These attributes make *Swift* a unique and powerful tool for the study of SNe Ib/c.

Ultraviolet/Optical Telesope



The *Swift*/UVOT is a 30 cm Ritchy–Chrétien telescope with six broadband filter, a white light filter, and two grisms. The grisms have spectral resolutions of approximately 18 Å/pix (UV grism, ≈1700–3500 Å) and 20 Å/pix (visual grism, ≈ 3500–6000 Å).

Table 1

Filter	λ_0 (Å)	FWHM (Å)	PSF (″)
V	5402	750	1.79
B	4331	980	1.91
U	3507	875	1.96
UVW1	2634	700	2.15
UVM2	2231	510	1.86
UVW2	2034	760	2.17
White	3507	2600	2.04

Selection Criteria

At present *Swift* is observing approximately five SNe Ib/c a year. Priority is given to supernova that are closer than $z < 0.01$ (≈50 Mpc). Supernovae more distant than this are usually too faint for UVOT to obtain light curves much more than approximately one week past maximum light. Targets should be young so that the UV/optical peak can be well sampled. Finally, candidate supernovae should be well isolated from their host galaxies so that contamination does not significantly affect the photometry. This is particularly important if *X*-ray observations are to be made. In practice this means that *Swift* will only observe a SNe Ib/c that is at least 8" from the nucleus of its host galaxy. These guidelines are intended to winnow out supernovae that will not produce high-quality data. In practice exceptions have been made in cases where an exceptional scientific return is expected. Other criteria that are considered in selecting supernova targets are the Galactic extinction towards the supernova and the impact on *Swift*'s gamma-ray burst observations.

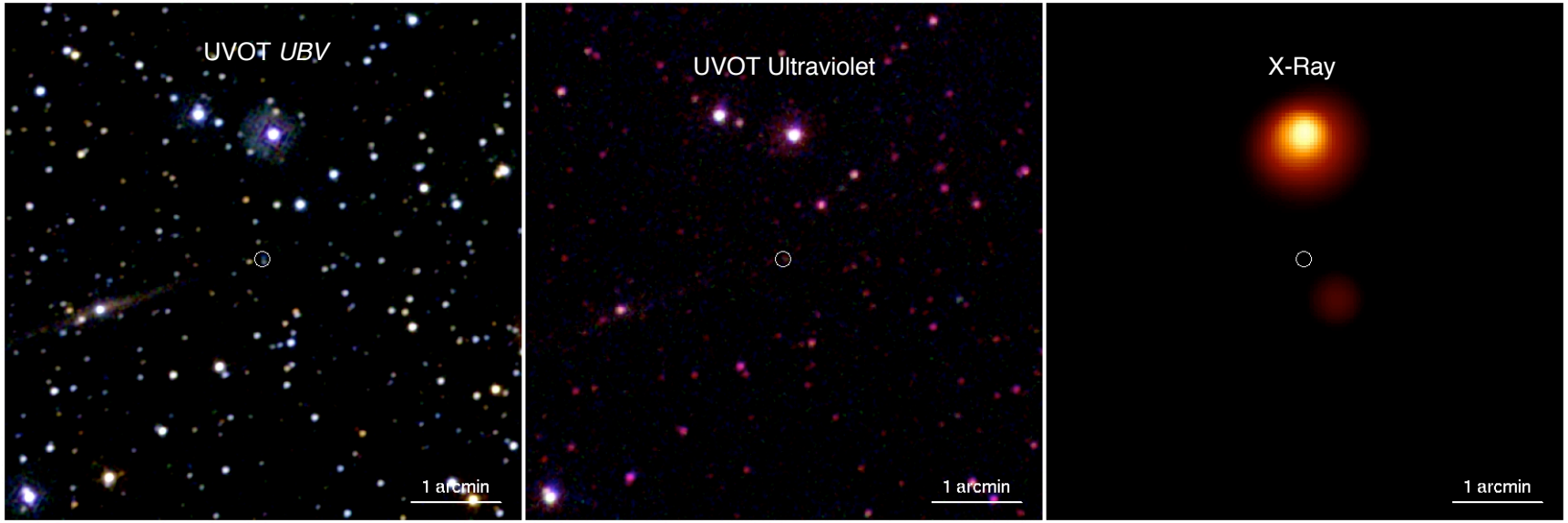
The *Swift* Supernova Team is open to observing any supernova that meets these criteria. To submit a request for time-critical observations please use the Target of Opportunity form at http://www.swift.psu.edu/too.html. A general call for targets will be made in Cycle 4 of the *Swift* Guest Investigator programme. Please see http://swift.gsfc.nasa.gov/docs/swift/proposals for more information on the guest investigator programme.

Table 2: SNe Ib/c observed by *Swift*

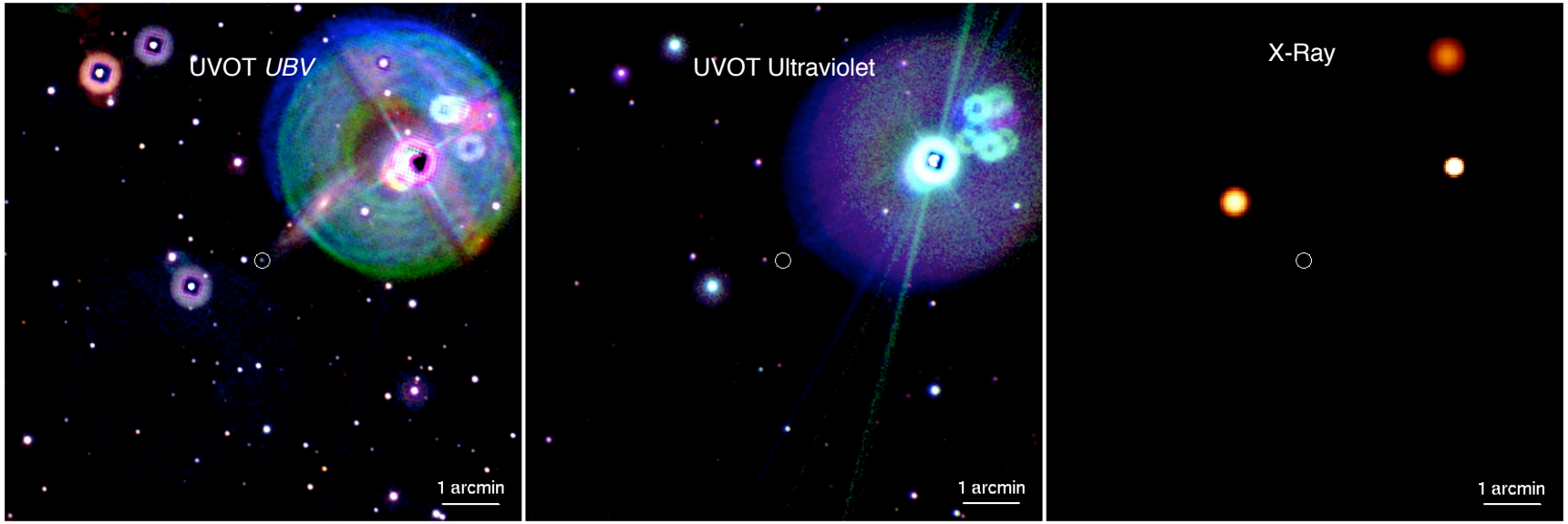
Supernova	Type	Distance (Mpc)	Host Galaxy
SN2007I	Ic	94	SDSS J115913.13–013616.0
SN2007D	Ic	99	UGC 2653
SN2007C	Ib/c	30	NGC 4981
SN2007lt	Ib	64	Anonymous
SN2006lc	Ib/c	68	NGC 7364
SN2006jc	Ib	24	UGC 4904
SN2006dn	Ic	71	UGC 12188
SN2006aj/GRB 060218	Ic	145	Anonymous
SN2005ek	Ic	69	UGC 2526
SN2005da	Ic	63	UGC 11301
SN2005bf	Ib/c	79	MCG+0–27–5

All of these supernovae were observed at least once by *Swift*. Only those that were bright and near maximum light were observed for extended periods. SN2006aj/GRB 060218 is the only target that has been associated with a gamma-ray burst.

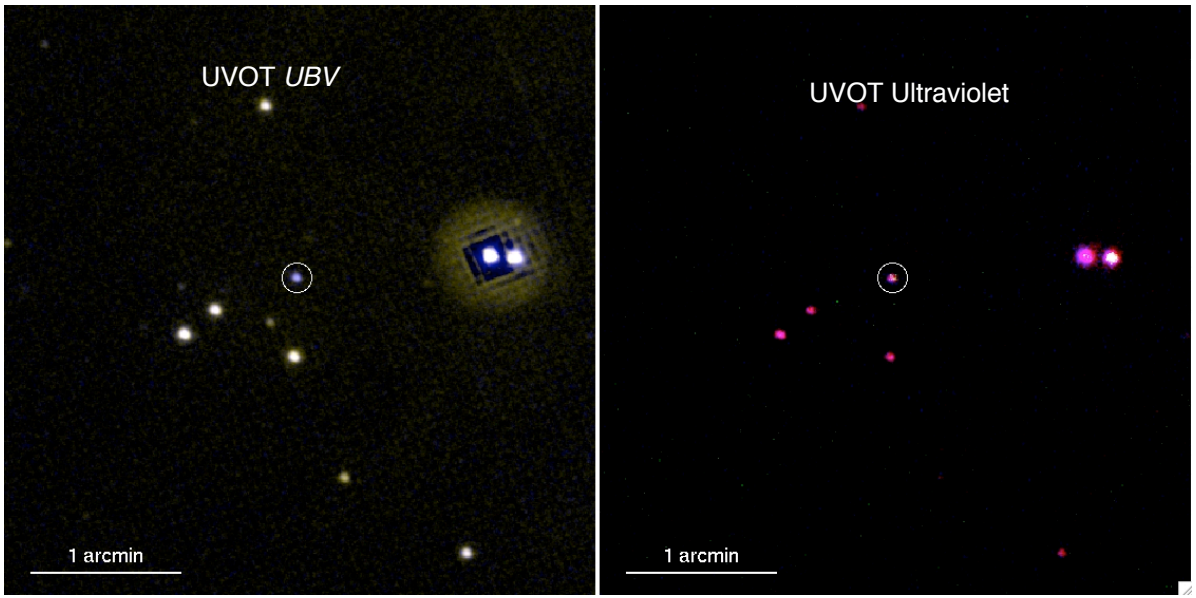
SN2005da



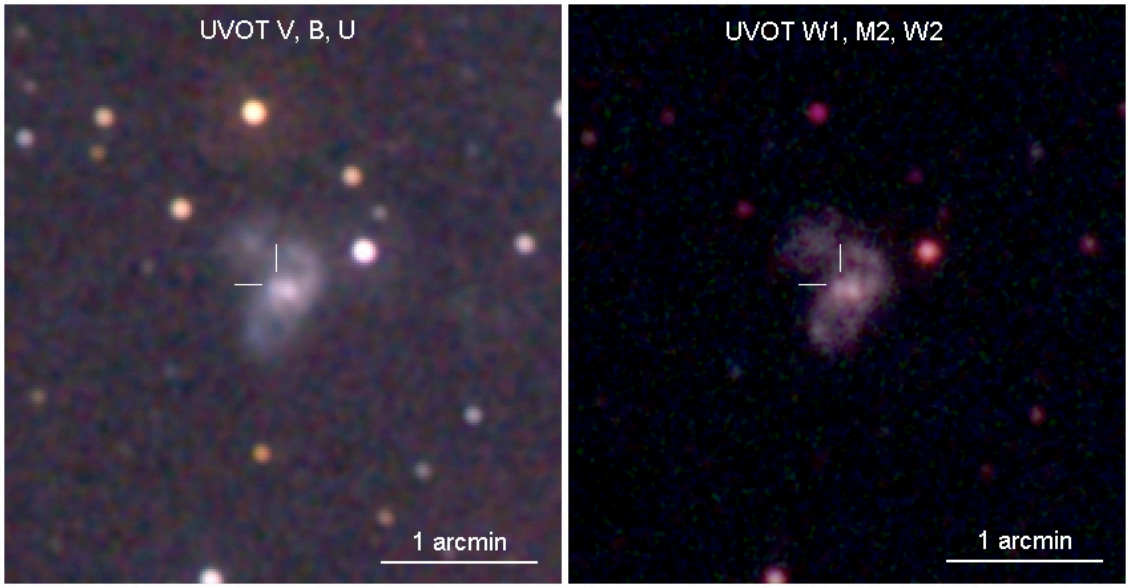
SN2005ek



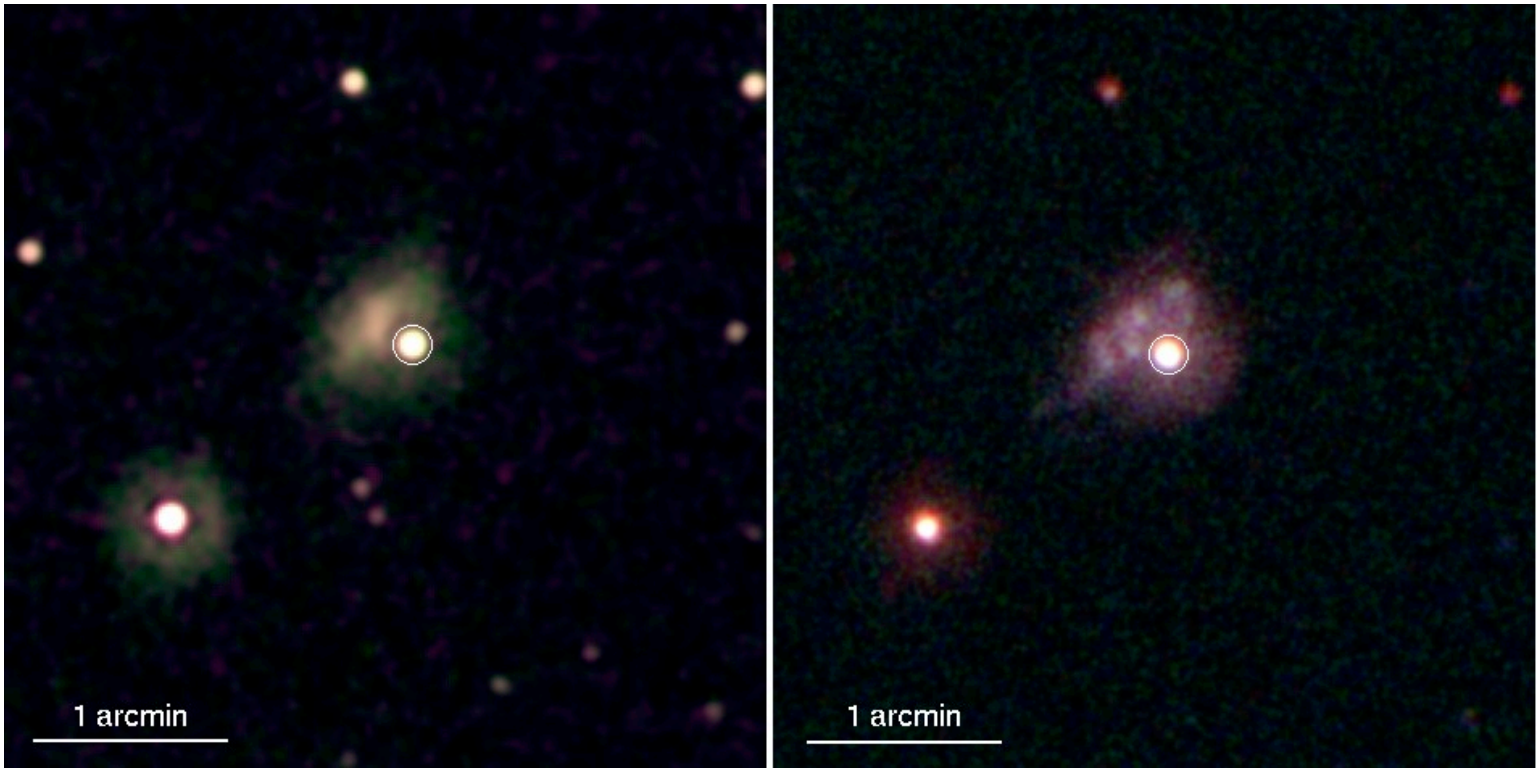
SN2006aj/GRB 060218



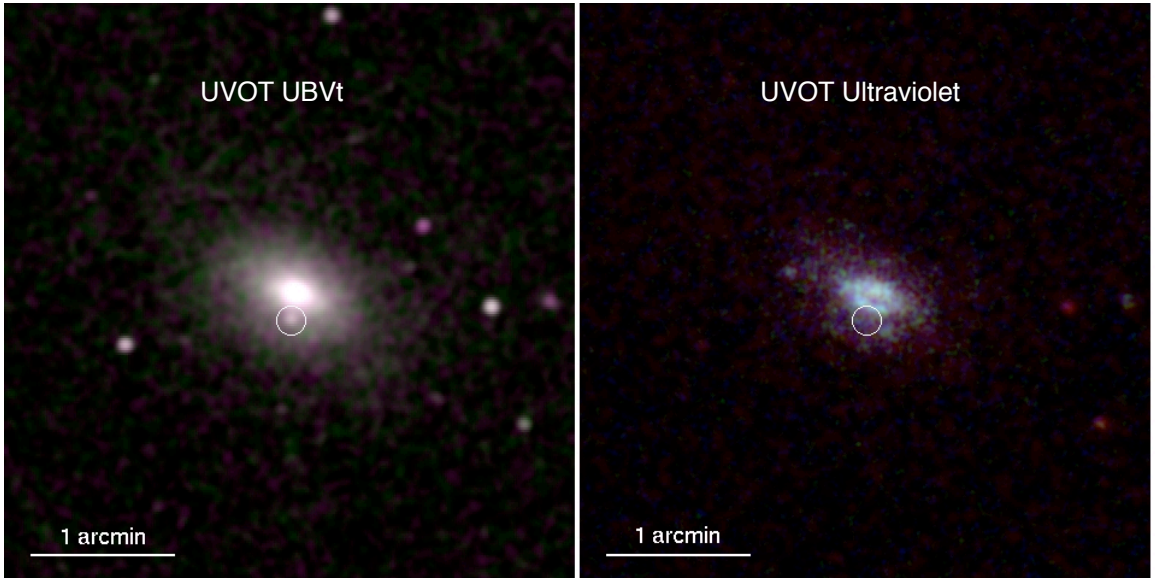
SN2006dn



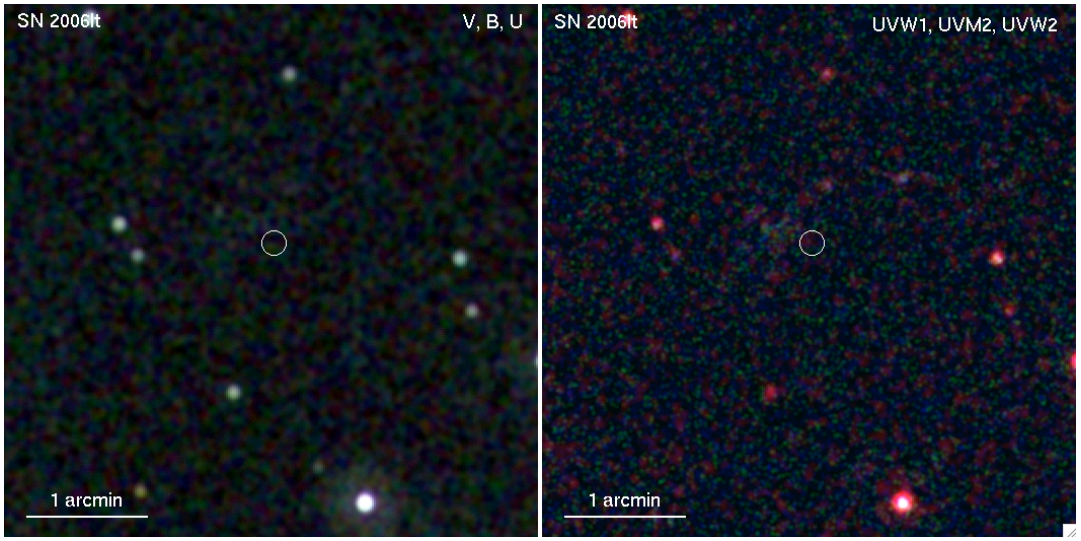
SN2006jc



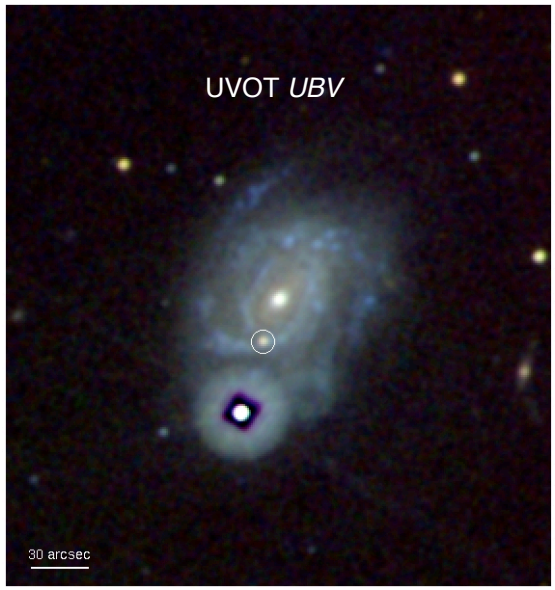
SN2006lc

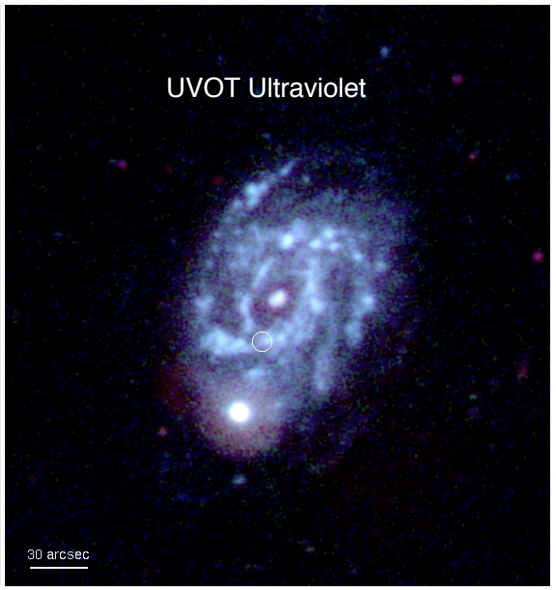


SN2006lt

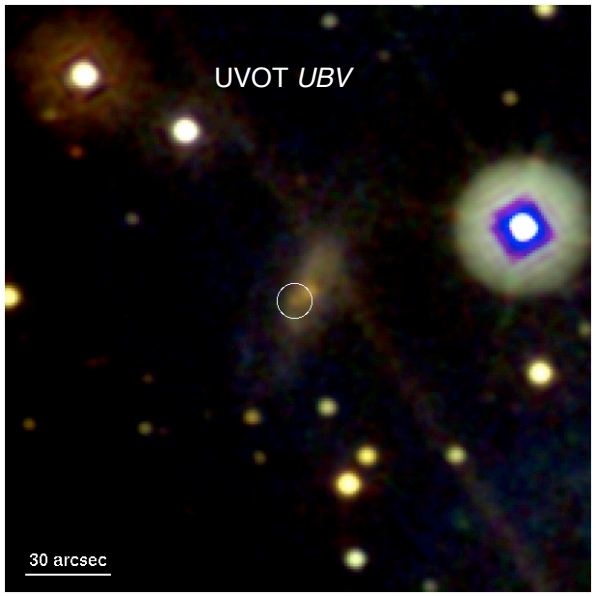


SN2007C

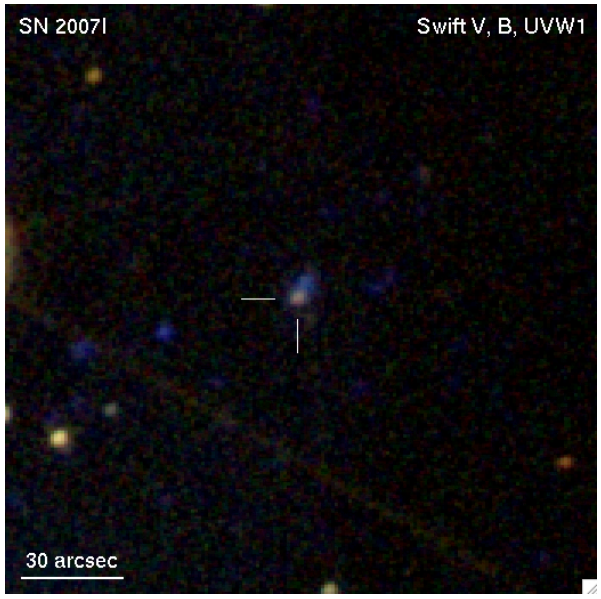




SN2007D



SN2007I

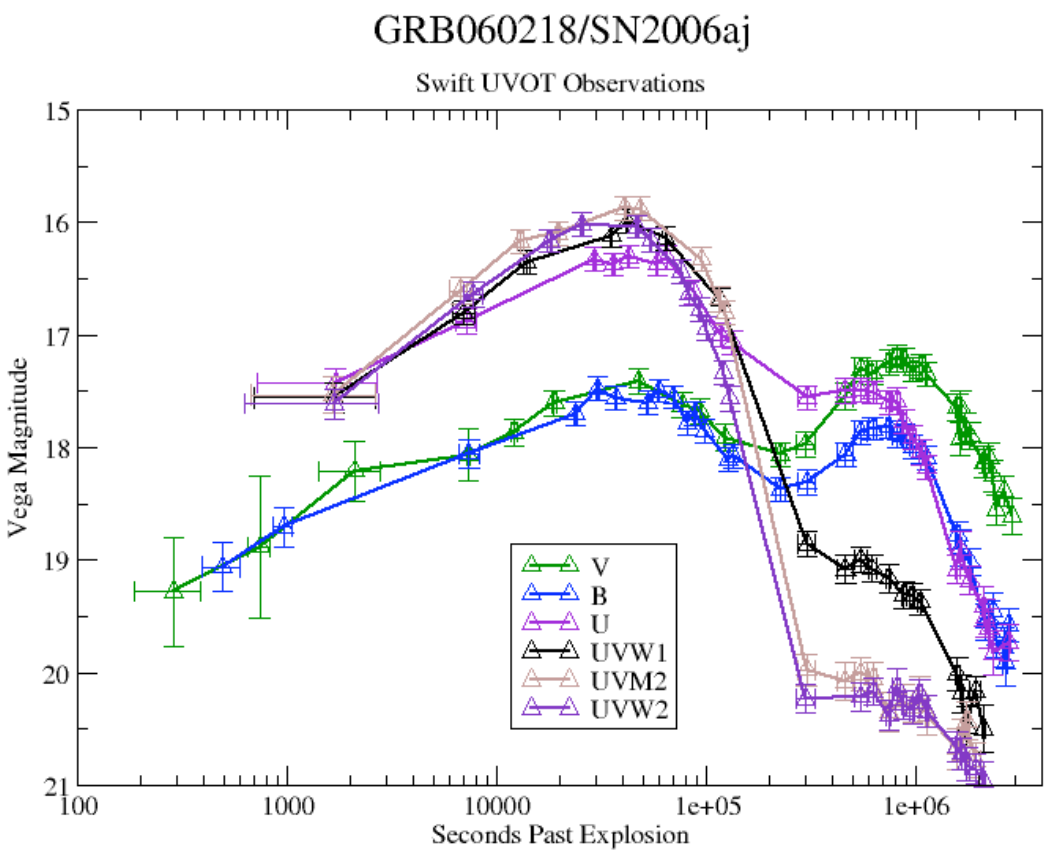


SN2006aj/GRB 060218

On 18 Feb 2006 *Swift*'s Burst Alert Telescope detected the unusual gamma-ray burst GRB 060218. This burst was later shown to have an associated SN Ib/c (SN2006aj). UVOT began imaging SN2006aj/GRB 060218 at 152 s after the BAT trigger. This was the first time that a supernova has been observed starting at essentially the moment of explosion. The early light curve of SN2006aj shows a bump at a few thousand seconds after the burst which has been interpreted as the shock breakout from the region where the stellar wind becomes optically thin. The ultraviolet light fades rapidly after this while the optical light fades much more slowly. There is a second, fainter, peak at approximately one week which corresponds to the traditional maximum light of the supernova. Unlike the first peak this one is much stronger at optical wavelengths than it is in the ultraviolet

SN2006aj does not show the "normal" gamma-ray burst optical afterglow behaviour (a power-law decay, possibly with bumps and breaks). Only the supernova component is seen in the light curve. This is reminiscent of SN1998bw/GRB 980425, where only light from the supernova was seen. In that case the lack of a traditional gamma-ray burst optical afterglow may have been a selection effect due to the delay between the gamma-ray burst and the identification of the supernova counterpart. For SN2006aj/GRB060218, however, we have observations starting 2.5 minutes after the burst, so we know that there was no traditional optical afterglow, just the supernova light.

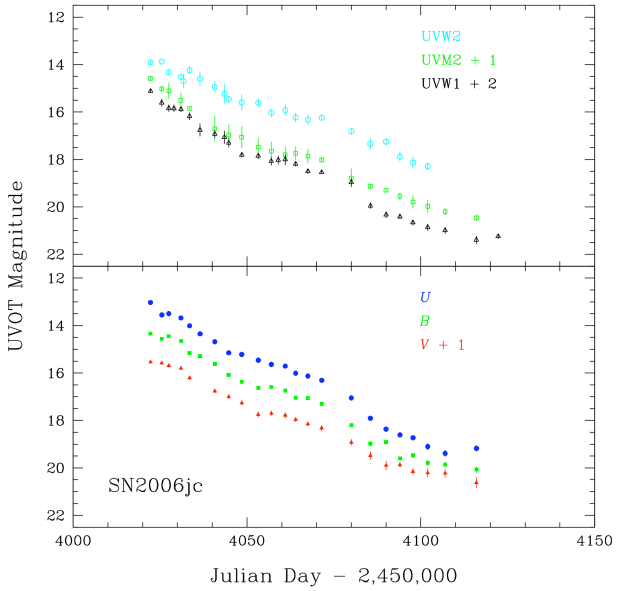
UVOT Light Curves for SN2006aj

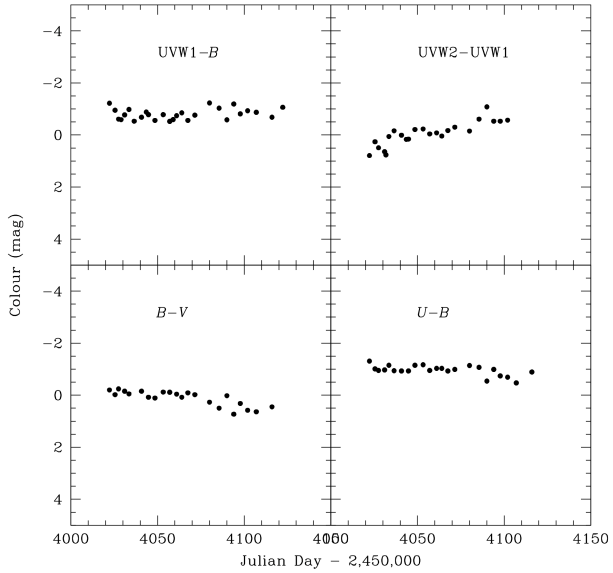


Swift observations of GRB 060218 began less than three minutes after the GRB trigger. The initial peak, at ≈45,000 s, has been interpreted as a shock breakout. This feature shows an approximately achromatic rise and chromatic decay. The second peak, at ≈10^6 s, (which is much weaker at UV wavelengths) corresponds to the traditional maximum light of the supernova. Note that there is no evidence of the standard power-law decay light curve that is usually associated with gamma-ray bursts. This is similar to SN1998bw/GRB 980425.

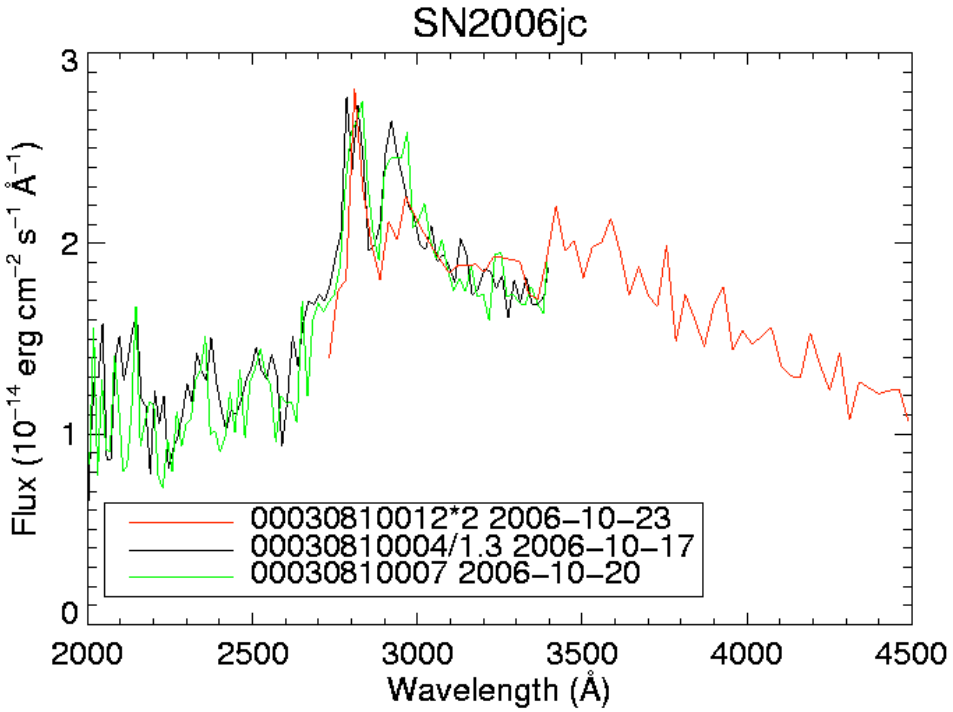
SN2006jc

Swift began observing SN2006jc a few days after maximum light and continued observing for several weeks. The light curves decay is approximately achromatic in each filter. The flattening seen beginning at approximately JD 2,454,090 is due to contamination from the host galaxy. No colour evolution is seen in the optical, but there is evidence that the ultraviolet colour (UVW2−UVW1) becomes bluer with time. We intend to take template observations of the host in 2007 or 2008 (after SN2006jc has faded to below the UVOT detection limit) in order to do image subtraction and refine the shape of the light curve. UVOT and XRT observations of SN2006jc are ongoing and will continue as long as *Swift* is able to detect this object.





Grism Spectra of SN2006jc



This Figure shows grism spectra of SN2006jc at three epochs. The emission features at ≈2800 Å is the Mg II doublet due to shock-heated circumstellar material. The corresponding absorption feature is the Mg II either in the host galaxy or in the Milky Way.

Grism observations with UVOT require that the source be fairly bright ($V <\approx 16$). SN2006jc had $V < 16$ for approximately 20 days.

Summary

The *Swift* Supernova Team has undertaken a project to obtain optical, ultraviolet, and *X*-ray observations of Type Ib and Ic supernovae in the local Universe. The goals of this programme are to use *Swift* data to understand the physics of these supernovae, and to probe their interaction with their environments. Since SNe Ib/c have been associated with some gamma-ray bursts we will also explore this connection.

To date one SN Ib (SN2006jc) and one SN Ic (SN2006aj/GRB 060218) have been followed by *Swift* for long enough to obtain detailed light curves. SN2006aj was followed from 154 s to one month after the explosion. This is the earliest that any supernova has been observed. SN2006jc has been observed for approximately 100 days starting shortly after maximum light. This makes SN2006jc the most extensively studied SN Ib in the ultraviolet.

It is expected that *Swift* will continue to observe a few SNe Ib/c each year over the next few years, dramatically increasing the sample of SNe Ib/c that have been studied in the ultraviolet.